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RESEARCH PAPER

The Potential Supply of Biomass for Energy from Hardwood Plantations in the Sunshine Coast Council Region of South-East Queensland, Australia

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Abstract Small community-based biomass energy systems sourcing feedstocks from local small-scale forests are common in the northern hemisphere but are few in Australia. Fine-grained analyses of feedstock availability are an important precursor to increased investment in these systems in Australia. This study presents estimates of the potential biomass for energy supply from hardwood plantations within the Sunshine Coast Council region of southeast Queensland. The region's 1,120 ha of private farm forestry, corporate-owned and joint venture hardwood plantations are predominantly small-scale (<20 ha) Gympie Messmate (*Eucalyptus cloeziana*) monocultures. Plantation age-class and corresponding area, productivity and management history findings and informed harvest-related assumptions underpin a 20-year forecast of biomass yields from a suggested plantation harvest schedule. The biomass yields are underbark stem-wood quantities assumed to be unmerchantable for higher-value solid-wood products. Future thinning (at age 12 years) and clearfell harvests (age 25 years) could provide minimum woody biomass yields of 30 and 108 GMt/ha respectively. Closer to 200 GMt/ha may be available from clearfell harvests of poorly-managed farm forestry plantations. The forecast annually available biomass supply is highly variable and mostly of small quantities.

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Biomass energy plants seeking a sustainable supply of feedstock must therefore access additional locally-available waste biomass. Further research is required to identify and quantify these sources. Field trials are also required to understand better the likely product mixes and available volumes of biomass for energy from the region's various hardwood plantations and to test for efficient integrated biomass harvest and supply chain systems for the sizes and terrains that are characteristic of these plantations.

Keywords Eucalypt plantations · Resource audit · Woody biomass · Bioenergy · Regional development

Introduction

The development of Advanced Wood Combustion systems, as defined in Richter et al. (2009), combined with ambitious national-level greenhouse gas mitigation and renewable energy targets, and concerns about energy costs and availability has stimulated increasing interest in the use of woody biomass for energy in many developed nations (Laitila 2008; Benjamin et al. 2009; BERC 2010; Valente et al. 2011; Stucley et al. 2012). In the cold climate zones of Europe and North America, many relatively small biomass energy plants generate heat or, less commonly, co-generate electricity and heat for local community applications such as apartment complexes, municipal buildings, businesses, schools, hospitals and universities (for examples see TEAG 2009; BERC 2010; Kalt et al. 2011). These systems require comparatively small quantities of biomass feedstock, hence their supply chains can be short and non-intrusive with small numbers of truck movements which assists with community support. Short payback periods are often another appealing feature of the installed small-scale biomass energy systems. Deployment of these systems creates new markets for woody biomass that can provide opportunities for improved management and utilization of local forestry resources and other sustainable development outcomes. For example, these markets can encourage timely thinning regimes which can improve forest health and productivity. New woody biomass energy markets can also increase financial returns to forest growers and support local and regional energy resilience, job creation, economic diversification and farm reforestation initiatives (Benjamin et al. 2009; TEAG 2009; BERC 2010; Valente et al. 2011).

Compared to many northern hemisphere nations, Australia has few small-scale community-based biomass energy systems in operation. Despite Australia's warmer climate, opportunities still exist for deployment of these bioenergy plants for local business, institutional and community space heating, hot water and steam, or combined heat and power applications. Many regions of the country now contain substantial native hardwood (eucalypt) plantations that could supply such plants with woody biomass feedstocks from various residues. The area of these plantations in all Australian states has increased rapidly over recent decades. For example, Queensland's hardwood plantation estate increased from 1,300 ha in 1992 (National Forest Inventory 1997) to 53,500 ha in 2012 (State of Queensland 2012). The new

plantings are mostly spread throughout the state's southern high-rainfall (i.e. more than 800 mm/annum) areas within 150 km of the coast. Most of these new plantings were established between the late 1990s and mid-2000s by forestry prospectus companies growing mostly pulpwood plantations. The Queensland Government's Department of Primary Industries-Forestry (DPI-F) established approximately 12,000 ha of long-rotation plantations for solid-wood production during this period (Last 2013). Private landowners engaged in mostly small-scale farm forestry have also contributed to the recent expansion of Queensland's hardwood plantation resource.

With current management approaches and markets, long-rotation hardwood plantations in Queensland are anticipated to have negative or marginal profitability (Venn 2005; State of Queensland 2012). The high up-front costs, continuing maintenance expenses and long wait for returns reduce the financial viability of these plantations and have constrained the uptake by farm forestry and larger-scale private investors (Spencer et al. 1999; Harrison et al. 1999; Emtage et al. 2001; Meadows 2011; State of Queensland 2012). The limited availability of regional-level productivity data, uncertainties about the quality of fast-grown plantation hardwood timber, and under-developed markets (GRO 1999; Lee et al. 2011), particularly for thinnings and other harvest residues (McGavin et al. 2006) are also key impediments. Reliable local markets for the full suite of materials available from commercial harvests are essential to reducing the financial risk to hardwood plantation investment in Queensland.

Timely thinning to reduce initially high stocking rates is essential silviculture for enhancing the high-value solid-wood potential of long-rotation hardwood plantations (Smith and Brennan 2006). A commercial return from thinning can be critical to the financial viability of these investments (McGavin et al. 2006). However, hardwood plantation thinnings typically include many small and defective logs that can have limited or no market applications (McGavin et al. 2006). Clearfell harvests will also include undersized and defective logs plus small tops from merchantable stems as well as other woody residues (i.e. large branches, stumps). These low-value or traditionally waste materials are ideally suited to conversion to woodchips for bioenergy use. Grower access to biomass energy markets for these chipped materials could render some thinning harvests cost-neutral or profitable and enhance the profitability of clearfell harvests (Magagnotti et al. 2011, 2012). This could encourage timely thinning regimes and investment in new plantations, thereby increasing the future availability of higher-value solid-wood products from a plantation growing region. Overseas experience (e.g. BERC 2010; Valente et al. 2011) suggests using the biomass supply from these plantations in local bioenergy plants throughout regional Australia could support national, state and local-level greenhouse gas mitigation, energy security and socio-economic development strategies.

Bioenergy policy-makers and investors require data on the availability of suitable feedstocks. Analyses of feedstock availability from hardwood plantations in Australia have typically been macro-level studies (for examples see O'Connell et al. 2009; Stucley et al. 2012; Farine et al. 2012). Finer-grained data is necessary to support investment in small-scale community-based bioenergy plants. This paper

reports on the potential biomass for energy supply from hardwood plantations within the Sunshine Coast Council region of southeast Queensland. The research first sought to determine the type, extent, locations, age-classes, management histories and productivity of the region's eucalypt plantations. These characteristics underpinned a forecast of potential biomass yields from a thinning and clearfell harvest schedule suggested for these plantations. Various yield-related assumptions and the potential for use of the biomass supply in local bioenergy plants are also briefly discussed. The findings provide hardwood plantation productivity and biomass yield data that can aid the decision-making of policy-makers and forestry and bioenergy industry investors on the Sunshine Coast.

The Study Area

The Sunshine Coast is a richly biodiverse region covering 3,127 km^2 within Queensland's subtropical south-eastern corner (SCRC 2010) (see Fig. 1). The landscape is characterised by coastal lowlands and floodplains in the east rising to the hinterland's picturesque rolling hills and fertile river valleys to the west. The region's high annual rainfall and moderate-high fertility soils make the extensive rural hinterland a highly suitable and potentially high-yielding hardwood plantation-growing region (GRO 1999; Venn 2005).

Hardwood Plantation Development in the Sunshine Coast Region

By the late-1990s the Queensland Government's *Hardwoods Queensland* research and development program (described by Venn 2005) had supported the substantial expansion of long-rotation eucalypt plantations on public land (i.e. State Forests) throughout southeast Queensland. Compared to the extensive plantings in surrounding regions, including the adjoining Gympie and Mary Valley districts, relatively small areas were planted in the Sunshine Coast hinterland. The Government has also supported private farm forestry development in the region, including through a sawlog plantation joint venture scheme that commenced in 1996 and offered shared equity and harvest rights between private landholders and DPI-F (Harrison et al. 1999). The region's joint venture and other DPI-F hardwood plantations are predominantly Gympie Messmate (*Eucalyptus cloeziana*) monocultures with an expected rotation length of 25–30 years (State of Queensland 2012). Planted at 1,000 stems per hectare (sph), silviculture has varied geographically but generally involved heavy pre-commercial thins (i.e. thinning to waste) over one or two stages by age 6 years to 200–400 final crop sph and form-pruning to 6 m on the best 200 sph (Last 2013). This regime is consistent with the view of thinning eucalypts 'hard and early' to produce large-diameter high-value solid-wood products within financially acceptable timeframes (Smith and Brennan 2006). Hancock Queensland Plantations (i.e. HQPlantations, a privately owned company managed by Hancock Timber Resource Group) now own and manage the region's former government-owned and joint venture commercial hardwood plantations. HQPlantations purchased the management rights to these assets in 2010.

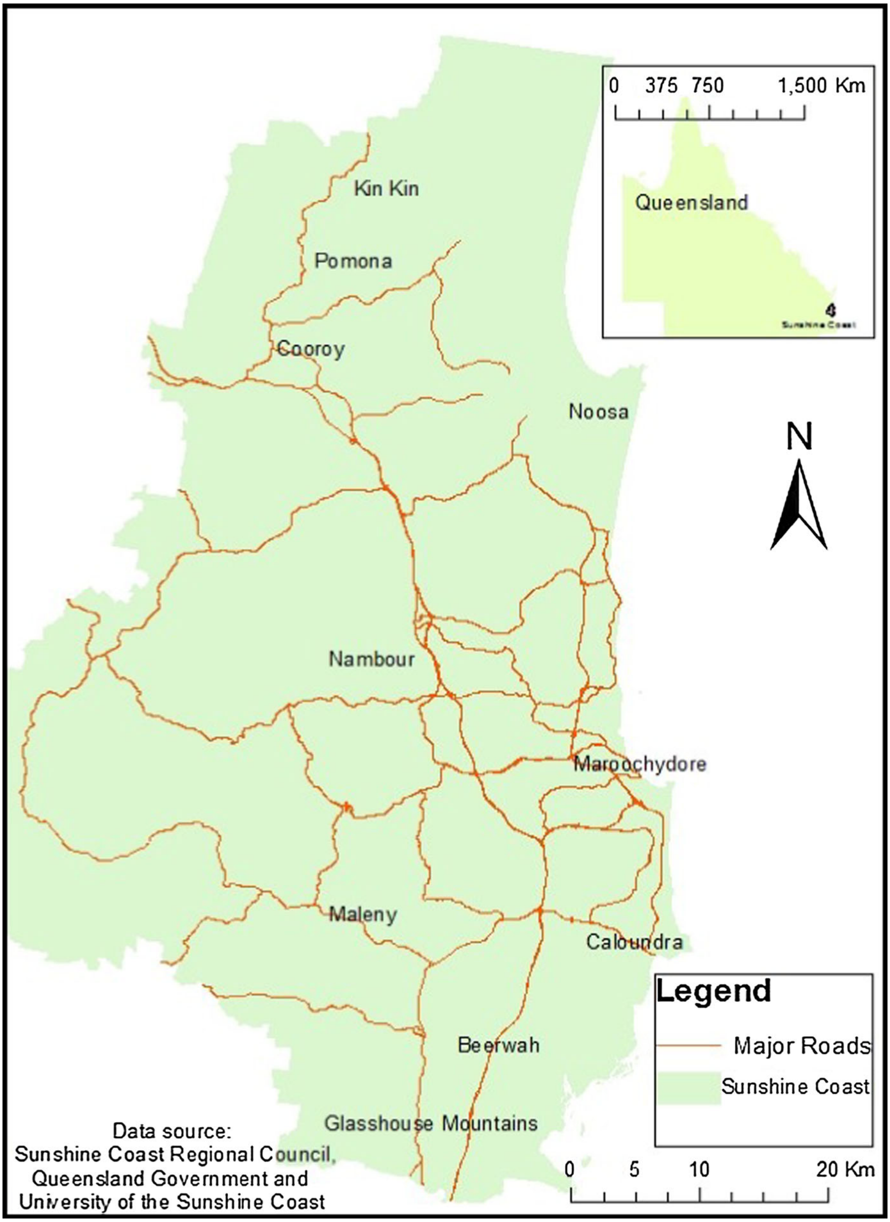

Fig. 1 The Sunshine Coast Council region

Support for private farm forestry has also been available to Sunshine Coast landholders through the Noosa and District Landcare group's Farm Forestry Program and more recently, through assistance schemes delivered by the Gympie-based former Regional Private Forestry Development Committee turned independent consultancy

Private Forest Service Queensland (PFSQ). These organisations have provided landholders with free or subsidised advice, trees and site-preparation assistance using devolved Federal, State and Local Government funding. The region's private eucalypt plantations are mostly small-scale (i.e. <10 ha) multi-purpose site-specific plantings using a mixture of locally-occurring species (Sewell 2013). Gympie Messmate is the most commonly planted species. Plantations have been established at between 833 and 1,111 sph. The thinning regime applied or recommended has generally been more conservative than that implemented in the now HQPlantations-managed plantations. This regime involves two or three lighter pre-commercial thins by age 8 years and an expectation of at least one commercial thin before a final harvest between ages 25 and 30 years (Shaw 2013). However, there is often little or no silviculture applied in the region's private farm forestry plantations that were established with a commercial intent (Sewell 2013), and particularly in the smallest of these plantations (Shaw 2013). This is commonly due to landowners placing a higher value on the aesthetic and environmental features of a developing plantation. The high turnover of rural properties in the region also leads to altered management objectives and decisions to not commercially harvest a plantation. A diversity of management objectives and applied regimes makes uncertain the future availability and quality of timber supplies from Queensland's private farm forestry resources (Emtage et al. 2001; State of Queensland 2012).

Research Method

Multiple data sources were used to investigate the extent and other characteristics of the Sunshine Coast's hardwood plantations and the potential biomass for energy yields from their future harvesting. These included a literature review, discussions with local forestry industry professionals, private consultants and farm forestry practitioners, analysis of existing plantation databases, and targeted plantation inventories. The productivity of the region's hardwood plantations was a particular focus of the data collection.

Existing Hardwood Plantation Productivity Data

The existing datasets included plantation type, location, age, area, management history, current stocking, average stem diameter (and range), mean dominant height (mdh) and stand basal area.

HQPlantations Data

HQPlantations provided productivity data for a sample of their corporate-owned and joint venture eucalypt plantations located on the Sunshine Coast. Twenty-nine plantation datasets across eleven age-classes ranging from 7.3 to 9.8 years were provided. The datasets are mostly of Gympie Messmate monocultures. Some Blackbutt (*Eucalyptus pilularis*) monocultures were also included. Most of the plantations have been subject to one or two heavy early-applied pre-commercial

thins. The plantations range in size from 2.4 to 44.86 ha and cover an area of approximately 340 ha. The datasets were gathered between 2003 and 2008. The plantations are mostly spread throughout the elevated parts of the Sunshine Coast hinterland. Some of the Blackbutt plantations are located on the coastal plain within Beerburrum State Forest[1].

PFSQ Data

PFSQ provided three productivity datasets for a 6.6-year old private farm forestry plantation located on former sugarcane-growing land of low elevation near Nambour. The plantation is a mixed-species planting of predominantly Gympie Messmate, Blackbutt, Spotted Gum (*Corymbia citriodora* subsp. *variegata*), Grey Gum (*E. propinqua*) and Swamp Mahogany (*E. robusta*). Other component species include Tallowwood (*E. microcorys*), Red Mahogany (*E. resinifera*), Ironbark (*E. crebra*, *E. siderophloia*) and Forest Red Gum (*E. tereticornis*). The plantation has been subject to one light pre-commercial thin. The three datasets were for different management units within the 12 ha plantation and were gathered in 2012.

Hardwood Plantation Inventory

The inventory work measured the productivity of a representative sample of the Sunshine Coast's eucalypt plantations. Plantations of varying species, age and applied thinning regime were targeted. Private farm forestry plantations more than 10 years-of-age were a particular focus of data collection.

Plantation Characteristics

Eighteen plantations located in the Noosa hinterland were measured between March and May 2013. These included fourteen private farm forestry plantations, one joint venture plantation and three HQPlantations-owned plantations. The plantations were aged between 8.3 and 34.2 years at measurement date. They were mostly Gympie Messmate monocultures or Gympie Messmate plantings with minor inclusions of species such as Blackbutt, Spotted Gum, Tallowwood, Flooded Gum (*E. grandis*), Grey Gum and Ironbark. Three were mixtures of these species and others including Forest Red Gum, Red Mahogany, Large-Fruited Red Mahogany (*E. pellita*) and Yellow Stringybark (*E. acmenoides*). The plantations were mostly <3 ha in size and up to approximately 15 ha. The total plantation area measured was approximately 57 ha. Characteristics of the measured plantations including applied thinning regimes are presented in Table 1. Most sites were established at 1,000–1,111 sph. Lower initial stockings (800–833 sph) and natural mortality were common in the unthinned stands.

[1] Beerburrum State Forest (surrounding the Beerburum-Beerwah-Glasshouse Mountains district) is the major hub of the Sunshine Coast's HQPlantations-managed 14,805 ha Exotic Pine (*Pinus spp.*) estate.

Table 1 Characteristics of the measured hardwood plantations

Location	Plantation type	Age (years)	Unit/area (ha)	Thinning regime	Stocking (sph)	Sampling intensity
Kin Kin	*E. cloeziana+*[a]	9	1–1.6	Light	550	10 %, 88 trees
		9	2–0.8	Light	520	16.5 %, 69 trees
		9	3–0.9	Light	475	17.7 %, 76 trees
Federal	*E. cloeziana*	12	4–0.366	None	697	28.1 %, 72 trees
		12	5–0.2	None	746	37.5 %, 56 trees
		12	6–0.346	None	669	32.8 %, 76 trees
	E. cloeziana	34.2	7–0.85	None	406	26.9 %, 93 trees
	Mixed species	20.2	8–1.1	None	642	17.7 %, 125 trees
Black mtn	Mixed species	15.4	9–1.25	Light	705	14.4 %, 127 trees
Federal	*E. cloeziana+*	12.4	10–2.4	None	680	9.2 %, 150 trees
Kin Kin	*E. cloeziana+*	8.3	11–3.1	Light	560	9.7 %, 168 trees
Ridgewood	Mixed species	14.2	12–1.4	None	690	14.9 %, 144 trees
Pomona (State Forest)	*E. cloeziana*	14	13–9.5	Heavy	246	8.7 %, 203 trees
Pomona (State Forest)	*E. cloeziana*	14	14–10.3	Heavy	233	8.5 %, 206 trees
Kin Kin (Joint venture)	*E. cloeziana*	12.8	15–14.7	Heavy	281	6.3 %, 263 trees
Pomona (State Forest)	*E. cloeziana*	18.1	16–7.5	Heavy	220	12.6 %, 208 trees
Kin Kin	*E. cloeziana*	18.2	17–0.9	Light	638	23.3 %, 134 trees
		32.2	18–0.12	None	400	100 %, 48 trees

[a] These are Gympie Messmate plantations with minor inclusions of other species

Plantation Measurement Strategy

Each plantation was firstly stratified into low-variability management units based on its management history and on-site observations. The size of a management unit determined the sampling intensity required to produce growth estimates of 10 % accuracy at a 95 % confidence level. To achieve this, Abed and Stephens' (2003) minimum recommendations for reliable forest measurements were exceeded. Plot sampling was primarily employed but a combination of plots and strip-line sampling was sometimes necessary due to irregular plantation shape or dense undergrowth restricting access and visibility. Plots and strip-lines were randomly located and evenly spread throughout a management unit to ensure representative samples of trees were obtained. All of the trees within one small 0.12 ha planting were measured. For the remaining plantations, an average of 17 % sampling intensity (i.e. percentage of total plantation area measured) was achieved.

The diameter at breast height over bark (DBHOB) of all trees within a plot or strip-line was measured using a diameter tape. The height of the two largest-diameter stems within a plot or strip-line was also measured using a Hagloff Electronic Clinometer and tape-measure. The average height of these trees was taken as the mdh of the

plantation (following Reid and Stephen, 1999). A Garmin GPS72 was used for strip-line length and area measurements. Notes on each plantation's site characteristics and associated tree performance, form and utilization potential were also recorded.

Plantation Productivity and Biomass for Energy Yield Calculations

The 50 plantation growth datasets were used to calculate each stand's average stem volume (m^3), total stand volume (m^3/ha) and volume mean annual increment (m^3/ha/year). The calculations were based on standard formulae reported by Reid and Stephen (1999) and Abed and Stephens (2003). The plantation productivity figures were calculated and analysed using Microsoft Excel spreadsheets.

Estimation of Plantation Volumes

Average stem volumes were calculated from stand average DBHOB and mdh using the formula: (DBHOB/200) × (DBHOB/200) × 3.142 × mdh/3. This formula provides a conservative estimate of the overbark volume of a tree's main stem (Reid and Stephen 1999). Total stand volumes were calculated by multiplying the average stem volume of the stand by the stocking rate. Volume mean annual increments (MAI) were calculated by dividing total volume by a stand age.

Biomass Yields for Energy Production

Plantation age-class and management history findings underpinned the suggested thinning and clearfell harvest schedule for the region's eucalypt plantations. The productivity findings, informed harvest-related assumptions and the areas of each plantation age-class supported the calculation of potential biomass for energy yields from these harvests. The biomass yield calculation applied to each plantation age-class followed five steps.

Step 1 Total plantation standing stemwood volume (m^3/ha) = plantation MAI × harvest age.

The applied MAIs are reduced averages of the productivity datasets at the harvest ages. Where necessary, datasets were projected to the harvest ages using an assumed average annual MAI increase of 0.5 m^3/year. This annual increase is consistent with later-aged projections in synthetic MAI curves developed by GRO (1999) for hardwood plantations in southeast Queensland. The resultant averages were reduced by 10 % to provide conservative underbark stemwood volume MAIs. The 10 % reduction more than accounts for the small difference between the applied volume equation form factor (i.e. 0.3) and the form factor of 0.2957 developed by Lee et al. (2011) for calculating an underbark stemwood volume for Gympie Messmate which is the dominant species in the region's plantations. The 10 % reduction therefore also tempers the MAI averages to account for the possibility that the productivity datasets are an above-average representation of the growth rates of the region's hardwood plantations. The assumed harvest ages of 12-years for commercial thinning and 25-years for clearfelling are consistent with a recommended generic

subtropical hardwood sawlog plantation regime of DPI-Forestry (2002, as cited in Venn 2005, p. 442).

Step 2 Timber volume harvested (m^3) = standing stemwood volume (m^3/ha) × proportion (%) felled.

The harvested volumes are 100 % of standing volume at clearfelling and an assumed 40 % of standing volume at a commercial thinning. The latter is consistent with recommendations for commercial thinning of 8 to 12-year old hardwood plantations in southeast Queensland (GRO 1999; Spencer et al. 1999; DPI-Forestry 2002 cited in Venn 2005, p. 442).

Step 3 Biomass m^3/ha = timber volume harvested (m^3) × biomass for energy percentage (%).

The biomass for energy percentage is the harvested stemwood volume assumed to be unmerchantable (i.e. undersized, defective) for solid-wood products. It is influenced by stand age, previous management and the harvest type. The applied percentages range between 40 and 50 % for thinning harvests and 25 and 40 % for clearfell harvests. These percentages are based on industry product-mix predictions for harvests of hardwood sawlog plantations in southeast Queensland (GRO 1999; Spencer et al. 1999; Venn 2005) and insights from the fieldwork supported by the productivity datasets.

Step 4 Biomass volume (green metric tonnes GMt/ha) = biomass m^3/ha × 1.1

The conversion ratio of 1 m^3:1.1GMt reflects the average 1100 kg/m^3 unseasoned timber density of Gympie Messmate, Blackbutt and Spotted Gum (as reported by Bootle 2004 and Wood Solutions 2011). These species are the species most commonly grown in the region's hardwood plantations.

Step 5 Total stemwood biomass tonnage available from future thinning or clearfell harvests of the plantation age-class = biomass yield (GMt/ha) × area (ha) of plantation age-class.

The area of each private farm forestry plantation age-class was reduced by 20 % to account for the expectation that a proportion of these plantations will never be commercially harvested or will perhaps only be thinned and not clearfelled.

Results

Hardwood Plantation Characteristics

The HQPlantations and PFSQ databases and information provided by private consultants suggest the Sunshine Coast contains at least 1,120 ha of eucalypt plantations. These include 598 ha of private farm forestry, 211 ha of HQPlantations-managed joint venture plantations and 311 ha of HQPlantations-owned plantations on State Forest and corporate freehold lands (Table 2). The plantations are mostly (i.e. 780 ha or 70 %) Gympie Messmate monocultures or Gympie Messmate with minor

inclusions of other species as described above. Other monocultures include 77 ha (7 %) of Blackbutt and 10 ha (1 %) that includes Dunn's White Gum (*E. dunnii*), Red Mahogany, Tallowwood, Sydney Blue Gum (*E. saligna*) and Yellow Stringybark plantations. The remaining 253 ha (22 %) are mixed-species plantations. The plantations are predominantly small-scale plantings (<20 ha).

About 750 ha (67 %) of the Sunshine Coast eucalypt plantations are located in the region's northern district (Noosa hinterland), particularly near the towns of Pomona, Cooroy and Kin Kin. The region's central district (Maroochy hinterland) contains 72 ha, mostly on the Blackall Range between the towns of Nambour and Maleny. The region's southern district (Caloundra hinterland) contains 175 ha with Blackbutt plantations located within Beerburrum State Forest comprising nearly half of this area. The location of about 120 ha of private farm forestry plantations was not confirmed. Most of the region's eucalypt plantations were established between 1997 and 2002 and in 2013 were aged between 11 and 16 years (Fig. 2).

Thinning and pruning are not commonly practiced in the region's private farm forestry plantations. Landholders explained this was often due to the costs, the lack of markets for thinned logs to at least recoup thinning costs and a reluctance to thin to waste. Limited forestry knowledge and not knowing who to contact or trust for management advice and contracting was also sometimes mentioned. From a commercial timber production perspective, many of the region's private farm forestry plantations are probably well-above optimal stocking rates for their age. This may not concern some owners whose plantations may have been planted for, or the primary objectives may have shifted to, goals such as property beautification, steep slope stabilisation, maintenance (mowing) reduction, and wildlife habitat (particularly for koalas, gliders and birdlife). Other plantations have been or will be only selectively harvested and sometimes only for on-farm fencing, light construction and firewood uses. These multi-purpose and non-commercial objectives also partially explain the low-level of thinning and pruning in private farm forestry plantations. In contrast, most of the region's joint venture and HQPlantations-owned plantations have been heavily thinned to waste and high-pruned by age 6 years. No commercial thins have been undertaken or are planned for these plantations (Last 2013). All of these plantations are expected to be available for clearfell harvesting.

Hardwood Plantation Productivity

The productivity findings varied widely, reflecting the diversity of plantation types, sites, ages and thinning regimes applied (see Tables 3, 4). The variation in MAIs ranged from a low of 3.5 m^3/ha/year for a lightly-thinned 6.6-year old poorly-performing unit within a mixed-species plantation on a low-elevation and poorly-drained former sugarcane-growing site to a high of 23 m^3/ha/year for an unthinned 34-year old Gympie Messmate monoculture on a steep and fertile hillside in the hinterland. The HQPlantations-owned and joint venture plantations generally had lower MAIs than the private farm forestry plantations of similar ages[2].

[2] No testing for statistically significant differences between the MAIs of the two plantation types was conducted as this was beyond the scope of the current study.

Table 2 Characteristics of the Sunshine Coast's hardwood plantations

Plantation category	Area (ha)	Plantation type and species	Plantation size (ha)
Farm forestry (private)	598	57 % (340 ha) *E. cloeziana* or *E. cloeziana+*	Typical—2–5
		42 % (253 ha) Mixed species	Largest—150
		1 % (5 ha) Other monocultures	Smallest—0.1
Farm forestry (HQPlantations joint venture)	211	96.5 % (204 ha) *E. cloeziana*	Average—12.3
		2.5 % (5 ha) *E. pilularis*	Largest—25.1
		1 % (2 ha) *E. dunnii*	Smallest—4.9
HQPlantations-owned	311	76 % (236 ha) *E. cloeziana*	Average—15.5
		23 % (72 ha) *E. pilularis*	Largest—44.9
		1 % (3 ha) *E. resinifera*	Smallest—2.3

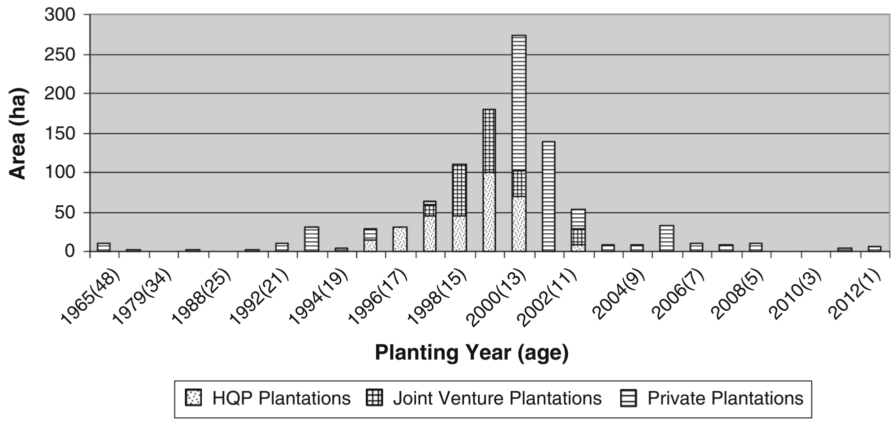

Fig. 2 Age classes and areas of the Sunshine Coast's hardwood plantations. Not included are 94 ha of private plantations known only to have been established sometime between 2000 and 2006

Discussion

Plantation Harvest Schedule and Biomass for Energy Yield Estimates

The suggested harvest schedule for the region's eucalypt plantations, harvest-related assumptions and potential biomass for energy yields are reported in Table 5. The harvest schedule applies to 903 ha of the region's currently 5 to 21-year old plantations to provide a 20-year forecast of biomass yields (Fig. 3). The 94 ha of private farm forestry plantations known only to have been planted sometime between 2000 and 2006 were excluded. This and the assumption that only 80 % of the area of each private farm forestry plantation age-class would be commercially harvested resulted in approximately 381 ha of the 598 ha of these plantations being included in the biomass yield forecasting.

The suggestion of immediate commercial thinning of the 12 to 18-year old private farm forestry plantations reflects the finding that thinning is not commonly applied in these plantations. Unthinned plantations in these age-classes would urgently require stocking reductions to maintain or restore their potential for yielding high-value solid wood products at future clearfell harvests. The 18 year cut-off age was applied on the assumption that growth responses of older unthinned plantations may be negligible on a 25-year rotation. Growth responses to thinning can be greatly reduced in long-overstocked hardwood plantations (Smith and Brennan 2006).

Differences Between the Applied MAIs

The applied clearfell harvest age (i.e. 25-years) MAIs are within the 15-20 m^3/ha/year range that industry experts predict for hardwood plantations in the Sunshine Coast region (GRO 1999; Venn 2005). The difference in the applied MAIs between the two plantation types is probably in part related to the different thinning regimes employed. Discounting site quality influences, it appears the heavy thinning in the HQPlantations-owned and joint venture plantations generally results in lower MAIs than in private farm forestry plantations at similar ages. Trees in the private plantations tended to have a lower average DBHOB and average stem volume but these plantations' higher stockings resulted in higher standing volumes and MAIs.

Biomass for Energy Percentage Assumptions and Yield Forecasts

The assumed 50 % biomass for energy proportion of thinnings from 12-year old plantations is taken from industry predictions of a 50:50 mix of posts and low-value woodchips from the thinning of 8 to 12-year old hardwood plantations (as reported by Spencer et al. 1999 and GRO 1999). The plantations aged 16 to 18-years potentially available for immediate thinning have had lower biomass percentages (45–40 %) applied on the assumption their higher proportions of larger stems could provide a greater recovery of solid-wood products. These biomass percentage assumptions result in yields of approximately 30–45 GMt/ha with approximately 8,750 GMt available from the suggested immediate thinning harvests. Additional yields of between approximately 200 and 800 GMt/annum will be available from 2014–15 to 2020–21 as the younger private farm forestry plantations reach commercial thinning age.

The assumed 25–40 % biomass for energy proportions of clearfell harvests are partly based on the predictions of Spencer et al. (1999) and GRO (1999). These authors suggest 25 % of the volume from a second commercial thinning and 10 % from a final harvest will be low-value logs suited to woodchips. As no second commercial thin is included in the proposed harvest schedule, these predictions suggest the forecast clearfell harvests could arguably yield up to 35 % stemwood biomass. A lower 25 % biomass assumption is applied to the HQPlantations-owned and joint venture plantations while 30 % is applied to the private farm forestry plantations. These assumptions result in biomass yields of approximately 110 and 115–125 GMt/ha respectively. The lower percentage applied to the HQPlantations-

Table 3 Productivity of the HQPlantations-owned and joint venture plantations

Plantation type	Thinning regime	Age (years)	Area (ha)	Stocking (sph)	Average stem volume (m^3)	Total volume (m^3/ha)	MAI (m^3/ha/year)
Gympie Messmate	Heavy	7.8	4.9	404	0.236	95.34	12.2
		8	4.6	242	0.154	37.27	4.67
			10.5	259	0.155	40.14	5.02
			3.1	377	0.152	57.3	7.15
			14.7	281	0.21	59.01	7.31
			14	399	0.203	80.99	10.13
		8.2	6.79	379	0.164	62.16	7.6
		8.4	22.3	229	0.193	44.18	5.25
			44.86	247	0.26	64.22	7.64
		8.7	4.5	264	0.393	103.75	11.92
			5.9	410	0.277	113.57	13.07
		8.8	18.8	442	0.195	86.19	9.77
			7.5	363	0.29	105.27	11.92
			10.9	445	0.321	142.84	16.23
		9.1	12.8	213	0.333	70.93	7.79
		9.3	26.9	281	0.364	102.28	11
		9.5	2.65	201	0.275	55.27	5.82
			4.72	304	0.253	76.91	8.1
			7.86	265	0.315	83.47	8.79
		9.8	2.8	303	0.298	90.29	9.22
			6.1	364	0.274	99.74	10.17
			4	469	0.231	108.34	11.06
		12.8	14.7	281	0.539	151.46	11.83
		14	10.3	233	0.641	149.35	10.67
			9.5	246	0.768	188.93	13.5
		18.1	7.5	220	0.888	195.36	10.8
	Light	7.3	4.1	710	0.096	68.16	9.32
			7.7	702	0.132	92.66	12.71
		7.8	12.8	524	0.13	68.12	8.73
			25.1	561	0.13	72.93	9.32
Blackbutt	Heavy	8	43	397	0.25	99.25	12.43
		8.7	2.4	385	0.26	100.1	11.49
		9.1	3.4	434	0.25	108.5	11.89

owned and joint venture plantations relates to the generally larger average DBHOB and average stem volume and the high-pruned treatment of the trees in these plantations that may result in a greater recovery of solid-wood products. A higher proportion of undersized tops could be expected in the private farm forestry plantations. Mixed-species plantings that were commonly observed to have a higher proportion of poorly-performing or failed stems plus the likelihood of a high

Table 4 Productivity of the private farm forestry plantations

Plantation type	Thinning regime	Age (years)	Area (ha)	Stocking (sph)	Average stem volume (m^3)	Total volume (m^3/ha)	MAI (m^3/ha/year)
Gympie Messmate and Gympie Messmate+	Light	8.3	3.1	560	0.233	130.48	15.72
		9	0.8	520	0.227	118.04	13.12
			1.6	550	0.326	129.8	14.45
			0.9	475	0.299	142.02	15.81
		18.2	0.9	638	0.474	302.41	16.62
	None	12	0.346	669	0.173	115.74	9.64
			0.2	746	0.172	128.31	10.69
			0.366	697	0.282	196.55	16.4
		12.4	2.4	680	0.242	164.56	13.29
		32.2	0.12	400	1.728	691.2	21.47
		34.2	0.85	406	1.945	789.67	23.09
Mixed-species	Light	6.6	2	528	0.044	23.23	3.52
			3.5	576	0.06	34.56	5.21
			6.6	544	0.112	60.93	9.26
		15.4	1.25	705	0.331	233.35	15.15
	None	14.2	1.4	690	0.231	159.39	11.22
		20.2	1.1	642	0.54	346.68	17.18

proportion of unpruned stems in farm forestry plantations could also result in higher biomass yields from these plantations. A higher biomass for energy proportion of 40 % has been applied to the assumed unthinned 19 to 21-year old private plantations. In-field observations confirm suggestions that unthinned or underthinned plantations at this age will contain a high proportion of undersized, suppressed and defective stems (Smith and Brennan 2006). The 40 % assumption results in a biomass yield of approximately 190 GMt/ha from the clearfell harvesting of these plantations. A total of approximately 6,680 GMt will be available from harvests of these plantations between 2017–18 and 2019–20. A peak in biomass availability from clearfell harvests of the region's other plantations will occur between 2022–23 and 2027–28. Yields of between approximately 5,500 and 27,800 GMt/year are predicted for this period.

Evidence suggests the industry predictions of 50 % solid-wood product recovery from 8 to 12-year old hardwood plantation thinnings may be optimistic. Best practice thinning of these plantations is 'from below' and would result in a high proportion of harvest volume consisting of small-diameter or poor-formed stems that would not meet solid-wood product specifications. Discussions with local forestry consultants (Sewell 2013; Shaw 2013) and a farm forest plantation grower from nearby northern New South Wales (Wright 2013) indicate substantial timber quality challenges and current marketing difficulties with young small-diameter posts from hardwood plantation thinnings. These factors contribute to the thinning to waste that is typical when thinning is practiced in the Sunshine Coast's private

Table 5 Hardwood plantation harvest schedule, assumptions and biomass for energy yields

Plantation type	Harvest type and harvest years	MAI at harvest age (m^3/ha/year)	Volume harvested (%)	Biomass for energy		Area available (ha)
				Biomass volume[a] (%)	Biomass tonnes/ha[b]	
Private farm forestry	Immediate thin of 12–18 years age-classes (2013–14)	11.5–14.2	40	40–50	30.3–44.9	263.5
	Thin current 5–11 years age-classes at age 12 (2014–15 to 2020–21)	11.5	40	50	30.3	82.56
	Clearfell current 19–21 years age-classes at age 25 (2017–18 to 2019–20)	17.3	100	40	190.3	35.12
	Clearfell previously thinned 5–18 years age-classes at age 25 (2020–21 to 2033–34)	17.3[c]	100	30	114.8–124.5	346.06
HQPlantations-owned and joint ventures	Clearfell current 11–18 years age-classes at age 25 (2020–21 to 2027–28)	15.8[d]	100	25	108.6	522

[a] The percentage of the harvested volume

[b] Green metric tonnes/ha (Gmt/ha)

[c] This MAI is used to calculate a plantation's total stemwood volume growth at age 25. The modelled previously thinned volumes have been deducted from this total volume to give a standing harvestable stemwood volume at age 25

[d] Thus MAI is based on growth data gathered after the plantations had been thinned to waste and therefore does not account for these removed volumes

farm forestry plantations. Hardwood plantations in the southeast Queensland region are a relatively immature resource, meaning there also remains much uncertainty about the quality, yields and value of fast-grown solid-wood products from future clearfell harvests of these plantations (GRO 1999; Venn 2005; Lee et al. 2011).

The biomass for energy calculations do not account for the materials that could be supplied from branch-wood. This exclusion of branch-wood and bark from the yield calculations, sought to ensure the proposed biomass removals did not include the trees' most nutrient-dense materials. It can be critical for these leaves, fine-branches and bark to be recycled on-site to avoid soil nutrient depletions and reductions in soil moisture-retention capacity that can degrade site quality and the sustainability of successive plantation rotations (Nambiar and Kallio 2008; Stucley et al. 2012; Berger et al. 2013). Large woody branches, however, could provide an

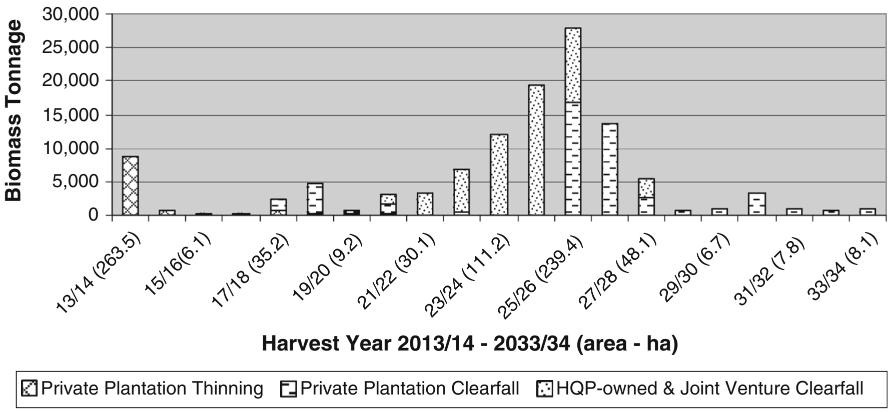

Fig. 3 Potential biomass for energy yields from future hardwood plantation harvesting (GMt)

additional source of biomass. In-field observations found such branches were most prevalent in the heavily and early-thinned HQPlantations-owned and joint venture plantations. Observations also suggest coppice regrowth from the stumps of previously thinned stems, regrowth of other native species (predominantly *Acacia spp*.) and infestations of the woody weed Camphor Laurel (*Cinnamomum camphora*) could provide additional woody biomass yields from some of these plantations.

Other Assumptions about the Forecast Biomass Yields

The forecast biomass yields assume none of the region's hardwood plantations will be severely damaged or fail due to environmental factors as has recently occurred elsewhere in eastern Australia (Lee et al. 2011). Long-rotation plantations are inherently exposed to substantial environmental risks including pest and disease incursions, fire, storms, cyclones and drought. These risks may also increase into the future given the predicted impacts of a changing climate (i.e. reduced rainfall, increases in temperatures and extreme weather events, altered pest and disease distribution and activity) in eastern Australia (Battaglia et al. 2009; Lee et al. 2011). Failed or damaged plantations could be abandoned or salvage harvested, thereby altering the proposed harvest schedule and forecast yields. The existence of biomass for energy markets would provide growers with an important opportunity for a financial return from materials that may be otherwise unmerchantable.

The forecast yields also assume it will be technically and financially viable to supply the harvested biomass to local markets. Hardwood plantation harvesting and supply chains are pioneering processes on the Sunshine Coast, and particularly for the region's farm forestry plantations. The small areas and often steep land of these plantations present particular challenges for the viable harvesting, extraction, processing and delivery of timber products to local markets. Biomass harvesting and supply systems appropriate to the varying characteristics of the region's hardwood plantations require development. Suitable systems could be adapted from the

knowledge and experience developed elsewhere in Australia (e.g. Ghaffariyan et al. 2011; Walsh et al. 2011) and throughout Europe (e.g. Karha et al. 2005; Laitila 2008; Ghaffariyan 2010; Valente et al. 2011; Magagnotti et al. 2011, 2012). An integrated harvest with higher-value products and short transport distances are keys to the efficient and economic utilisation of woody biomass for energy.

The Potential for Use of the Biomass Supply in Local Bioenergy Plants

The Sunshine Coast's hardwood plantations have potential to supply biomass feedstock to a local bioenergy industry. Use of this biomass in small community-based bioenergy plants for heating, hot water and steam, or combined heat and power applications would strongly support the regional Council's sustainability and economic development agendas (SCRC 2009). However, the 20-year forecast's high variability in annual biomass supply and the generally low to very-low volumes available (Fig. 3) precludes the deployment of local bioenergy plants relying solely on the plantation estate for feedstock. The forecast yields could be augmented by an expanded plantation estate and various additional locally-available sources of waste woody biomass. Previous research has reported the substantial potential for new broadscale long-rotation hardwood plantations (Spencer et al. 1999) and smaller farm forestry plantings (Meadows 2011) throughout the Sunshine Coast hinterland and on parts of the coastal plain's former sugar-cane growing lands (McDonald et al. 2006). Productivity data reported in Table 4 confirm this potential on some well-drained ex-caneland sites. Short-rotation woody crops could also be considered for some sites to provide shorter-term supplements to the biomass forecast. Other immediately available materials are also required and preliminary investigations suggest approximately 10,000 air-dry tonnes/annum of waste processed timber could be diverted from the region's landfill centres (Straker 2013). Further work is needed, however, to understand better the characteristics of this material and various other potentially available sources and their suitability for use in local small-scale community-based bioenergy plants.

Concluding Comments

This study has found the Sunshine Coast region contains at least 1,120 ha of predominantly small-scale Gympie Messmate monoculture plantations. Approximately 600 ha are private farm forestry plantations with the remainder being corporate-owned (i.e. HQPlantations) or joint venture plantings between HQPlantations and private landowners. Evidence suggests best-practice silviculture is not commonly applied in the region's farm forestry plantations, meaning many are suited to immediate commercial thinning. An opportunity for improved financial gain through local bioenergy markets could increase these plantation owners' willingness to thin while also enhancing this resources' potential to deliver future high-value solid-wood products. In contrast to the farm forestry plantations, the HQPlantations-owned and joint venture plantations have typically been thinned to waste and high-pruned by age 6 years and are not expected to be commercially thinned.

The study suggests that future thinning (at age 12 years) and clearfell harvests (age 25 years) of the region's plantations can provide woody biomass yields of at least 30 and 108 GMt/ha respectively. Closer to 200 GMt/ha may be available from clearfell harvests of unthinned or underthinned and unpruned farm forestry plantations. The calculation method and uncertainty surrounding the quality and yields of higher-value solid-wood products from future commercial harvests means the suggested biomass yields may be conservative. Detailed harvesting trials are required to understand better the likely product mixes and available volumes of biomass for energy from the region's hardwood plantations of differing composition and management history. These field trials should also test for efficient integrated biomass harvest and supply chain systems for the sizes and terrains that are characteristic of the region's plantations.

With supply chain development, the Sunshine Coast's hardwood plantations could contribute feedstock to a local bioenergy industry. However, the uneven spread of plantation age classes and their differing management histories make the annually available biomass supply over the forecast period highly variable and mostly of small quantities. The Sunshine Coast's current hardwood plantation estate is therefore just one component of a larger regional (and adjoining region's) biomass feedstock resource that a bioenergy industry must access for a secure and sustainable biomass supply. Any specific project plans require further investigation of the likely yields from additional plantations and other potentially available sources of feedstock. In addition to landfill diversions, these sources could include the region's industrial softwood estate, mixed rainforest species plantations, private native forests, woody weed (particularly Camphor Laurel) control programs, horticultural and agricultural crop residues, and the arborist and timber processing industries. Research is also required to determine the location, extent and costs of local energy demand. This can then be matched with projections of the region's total annual sustainable yield of woody biomass to identify appropriate sites and applications for local small-scale community-based bioenergy plants.

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